

A Process for Improving Early Life Failure Response

by

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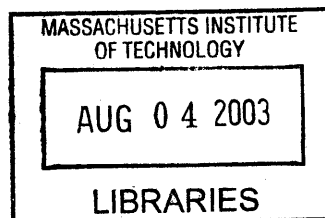
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ABSTRACT

Early life failures, products that fail within the first three months of operation, are an important measure of product quality and have significant impact to customer satisfaction. In any company, business processes should exist so that quality can be improved based on early life failures. This study was done as part of a seven-month internship aimed at improving such business processes at Sun Microsystems through the Leaders for Manufacturing program at MIT.

A business process for returns at Sun Microsystems involves global returns logistics, data analysis, and failure analysis, while taking the statistical behavior of early life failures into account. Cost of quality, coordination of activities within a company's functional groups and external manufacturers, and change management are factors that should also be considered. This thesis presents an analysis of current business processes, identifies gaps in the process, and suggests actions towards the implementation of a working process.

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Chapter 1. Introduction

As a leader in the innovation of servers and server systems, Sun Microsystems is now challenged to make quality a competitive advantage in the industry. At Sun Microsystems, early life failures (ELF), defined as products that fail within the first three months of installation, will be an important measure of product quality and customer satisfaction. Current and future products and manufacturing processes may be improved based on findings in ELF data. Moreover, Sun's ability to respond efficiently to an early life return through a clearly defined business process is valuable in streamlined and cost-effective operations.

Generally speaking, there are two aspects to ELF: a business process problem and an engineering problem. A business process must be defined for ELF returns so that roles for reverse logistics and failure analysis can happen effectively and efficiently.

Engineering is required not only to find the root cause of a problem, be it electrical, mechanical, or process-oriented, but also to analyze ongoing symptom and failure data to proactively improve products and processes.

Problem Statement

Redesigning the returns process at Sun Microsystems involves global returns logistics, data analysis, and failure analysis. As one might expect, structures and processes already exist in the company to receive failed units and to implement change. However, individual cases on how to find failed units and how specifically to do data analysis show that an efficient working business process does not exist. Identifying and implementing a working business process is not simple because of the complexities in microelectronics root cause analysis, complicated data and material flows, and change implementation.

The initial goal of this project was to understand and improve early life failure response processes. Given the limited time of the internship, a short list of concrete goals was created for the seven-month internship. The deliverables were: 1) maps of the current and ideal end-to-end returns process, 2) a data analysis procedure for the process and 3)

recommendations on how to improve ELF. The problem statement remained “How can Sun better respond to early life failures?” The reader may note that the question “How can early life failures be reduced in number?” is considered a part of the response process; operations and the organization as a whole first requires a framework for response, analysis, and corrective action for ELF, so that quality can be improved on a systemic basis.

Chapter 2. Background

2.1 Sun Microsystems

2.1.1 Company Description

Sun Microsystems, Inc. was founded in 1982 by Scott McNealy, Bill Joy, Andreas Bechtolsheim, and Vinod Khosla in Palo Alto, California. Since its beginning, Sun (which derived its name from the Stanford University Network) has pushed its single vision forward: “The Network is the Computer™,” and has been a pioneer in network computing. Sun’s first computer included a TCP/IP connection for networking, and employees have used email from day one.

Sun experienced rapid growth through the eighties and nineties, fueled by the rapid expansion of the Internet and increasing demand for high-powered, reliable servers. Today, Sun employs approximately 39,000 employees and has a global presence. For the FY 2002, revenues were \$12.5 billion.¹ Scott McNealy is the current CEO.

Sun has an extensive product line offering multi-million dollar high-end servers, mid- and low-end servers, workstations and data storage systems. All of Sun’s hardware products are based on the SPARC microprocessor. Sun also sells software, most notably, Solaris (a UNIX operating system) and Java.

Sun’s primary competitors in hardware are IBM, Compaq, HP, and Dell. With Sun’s recent entry into storage devices, EMC has also become a competitor. In software, Microsoft is Sun’s principal competitor.

Sun has based their external strategy on the three principles they refer to as their “three big bets” as outlined below²:

¹ Financial statements for Sun Microsystems at Yahoo! Finance Website. Available from <http://biz.yahoo.com/fin/l/s/sunw.html>.

² Ed Zander, “Three Big Bets,” Sun Microsystems, Inc. Website. Available from <http://www.sun.com/dot-com/perspectives/threebets.html>.

Massive scalability – The ability to scale the bandwidth, processing power, and storage capacity of servers to meet the demands of the Net economy.

Continuous real-time access – Design software, build systems, and provide support services that eliminate downtime and deliver real-time responsiveness enabling people to have continuous access to the Net.

Integratable stack – Create an integrated hardware and software stack for the backend network where the microprocessors, storage, system software, and middleware are all seamlessly integrated.

Sun uses an outsourced manufacturing strategy for their volume product lines. They retain most of the design work in-house and use external manufacturers to build and integrate the hardware. Sun maintains direct sourcing ownership of core parts such as the SPARC microprocessor, and critical parts such as boards used in their systems. They allow the external manufacturers to source non-critical components such as resistors from Sun-approved suppliers. Sun works hard to maintain strong relations with their core supply base while continuing to provide innovative, cost effective solutions to their complex sourcing needs.

2.1.2 Sun's Overall Quality Strategy and ELF

Sun's quality strategy is to provide servers and systems of high quality to customers. ELF must be minimized to meet this goal. Sun's current metric for measuring product quality in the field is Dead on Arrival (DOA), which measures failures within the first 72 hours of installation. In particular, units in the Asia-Pacific region are monitored for DOA by third-party contract manufacturers/partners in Japan who perform the diagnosis and collect data on DOA cases. Sun intends to augment measuring product quality with DOA by ELF in 2003-2004.

Compared with DOA, ELF is a significantly more challenging problem. We will consider DOA to be a subset of ELF. Obviously, the number of ELFs will be greater than the number of DOA units because of the longer time elapsed since installation. ELF logistics and data will be more challenging than those for DOA because the company intends to track individual ELF cases globally, as opposed to DOA, which has seen

primarily a regional implementation in the Asia-Pacific region. The root causes associated with ELF may be more numerous, more complex, and more subtle than those associated with DOA since ELF occurs over a longer period of time.

2.1.3 Sun's Volume Products and the Volume Products Operations Division

The work for this thesis was performed in Volume Products division of Sun Microsystems, located in Burlington, Massachusetts. Sun's Volume Products are their low- to mid-range servers. These products include the Sun Fire line of servers, which contain up to 8 ULTRASPARC processors. The operations group of the Volume Products division, which includes manufacturing and supply chain management functions, initiated this ELF effort. Managers in operations have the primary responsibility for ELF quality issues when ELF levels are too high. The rationale behind managers as the first line of defense is that ELF problems are often related to manufacturing processes.

Much of the manufacturing for the Volume Products division is outsourced to external (contract) manufacturers. These manufacturers do the board- and assembly-level manufacturing of the servers. Equipment used to test and diagnose systems is located at these partners' manufacturing sites. Functional groups involved in the returns process include operations (manufacturing and supply chain management), quality, engineering (development), customer service, and external manufacturers.

2.1.4 Servers

The server-class computers of today derive their name from the client/server network architecture created at Xerox PARC in the early 80's.³ The client/server model is based on distributed computing systems (clients) that run local versions of software connected to central repositories of data and information (servers). A server is simply a computer dedicated to serving a single task such as storing files (file server), managing printing (print server) or controlling network traffic (network server). Any computer can be used as a server. However, with the increasing demand for processing power and reliability, a

³ PARC History, PARC Company Website. Available from <http://www.parc.xerox.com/history.html>.

server computer today typically refers to a class of computers defined by high I/O bandwidth, massive processing power, and exceptional reliability, availability, and serviceability.

The basic architecture of a server is similar to those found in any other computer systems. The core of the server system is the microprocessor(s). A server often uses more than one microprocessor within the system; some of the larger systems integrate over 100 microprocessors.⁴ The processors are connected together and to local random access memory (RAM) by complex circuit boards that implement either bus-based or switch-based interconnection protocols. Due to the high bandwidth requirements, many servers use the more complex switch-based protocols such as the crossbar switch or a non-uniform memory access (NUMA) switch. The processor and memory are connected to other devices and to the network through industry-standard protocols and interfaces. The storage devices (hard drives) are connected using Fibre Channel, Infiniband, SCSI or Gigabit Ethernet connections. The hard drives can be either local to the server or remote. Other I/O devices, such as graphic cards, modems, keyboards, and mice and network access can be connected to the server through multiple PCI slots, USB ports and Ethernet connections.

2.2 Literature on Early Life Failures and Returns Processes

2.2.1 Early Life Failures⁵

The lifetimes of a population of servers of may be described using the bathtub curve, which plots the failure rate of the population versus time. Figure 2-1 shows a sample bathtub curve.

⁴ Sun Fire[tm] 15K Server, Sun Microsystems, Inc. Website. Available from <http://www.sun.com/servers/highend/sunfire15k/>.

⁵ D. J. Wilkins, "Hot Topics, The Bathtub Curve and Product Failure Behavior Part One - The Bathtub Curve, Infant Mortality and Burn-in," Reliability HotWire, Nov 2002.

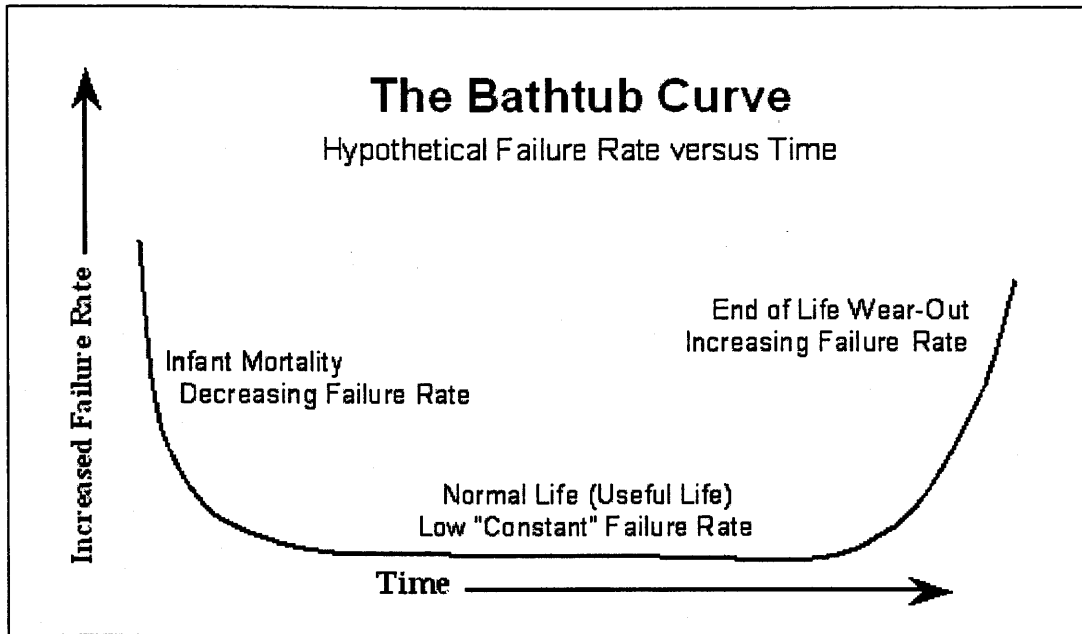


Figure 2-1: The Bathtub Curve. Ref: Dennis J. Wilkins, "Hot Topics, The Bathtub Curve and Product Failure Behavior Part One - The Bathtub Curve, Infant Mortality and Burn-in," Reliability HotWire, Nov 2002.

Some individual units will fail early (infant mortality failures) while others will last until wear-out. Failures during the infant mortality period are highly undesirable because they negatively impact customers' first impressions. ELFs are always caused by defects and mistakes: material defects, design mistakes, errors in assembly, etc. Normal life failures are normally considered to be random cases of "stress exceeding strength." Wear-out is due to fatigue or depletion of materials (such as lubrication depletion in bearings).

The actual time periods for these three characteristic failure phases can vary greatly. Infant mortality does not mean "products that fail within 90 days (or any other defined time period)." The infant mortality period is the time over which the failure rate of a product is decreasing and may last for years. Conversely, wear-out may not occur only after the expected product life. Wear-out refers to defects that occur when the failure rate is increasing, and in some products it has been observed after just a few months of use.

The Weibull Distribution

The Weibull distribution is given by:

$$f(x) = \frac{\beta}{\theta} \left(\frac{x}{\theta} \right)^{\beta-1} \exp \left[- \left(\frac{x}{\theta} \right)^{\beta} \right]$$

where $f(x)$ is the failure rate at time x . This distribution can be used to characterize failure probability in all three phases of the bathtub curve. β is the shape parameter and θ is the scale parameter. $\beta < 1$ models a failure rate that decreases with time, as in the infant mortality period. $\beta = 1$ models a constant failure rate, as in the normal life period. And $\beta > 1$ models an increasing failure rate, as during wear-out. There are several ways to view this distribution, including probability plots, survival plots, and failure rate versus time plots. The bathtub curve is a failure rate versus time plot.

Typical infant mortality distributions for state-of-the-art semiconductor chips follow a Weibull model with $0.2 < \beta < 0.6$. An example of a failure rate versus time plot is shown in Figure 2-2.

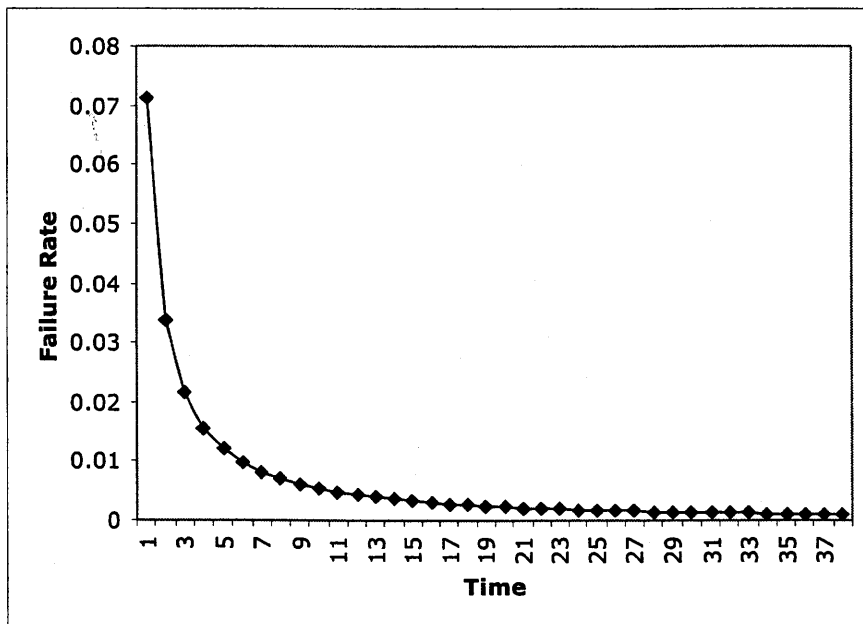


Figure 2-2. A sample Weibull distribution. This distribution can be used to model infant mortality (Failure Rate vs. Time). $\beta < 1$. Failure rates and times do not refer to any specific population.

This plot shows the distribution for a β value typical of complex, high-density integrated circuits (VLSI or Very Large Scale Integrated circuits). Parts such as CPUs, interface controller and video processing chips often exhibit this kind of failure distribution over time. If one ran these parts for the equivalent of three years and discard the failed parts, the reliability of the surviving parts would be much higher out to ten years. In fact, until a wear-out mode occurs, the reliability would continue to improve over time.

Burn-in for Leading Edge Technologies

Burn-in is a step in which units are stress tested to remove early life failures prior to shipping. Burn-in can improve the perceived reliability of high tech parts. Figure 2-3 shows the failure rate of a population which underwent burn-in (top curve) and a population that did not (bottom curve) based on the Weibull distribution described above. In this case, of all failures that occur in the first 20 years (about 4%), most failures occur in the first year or so.

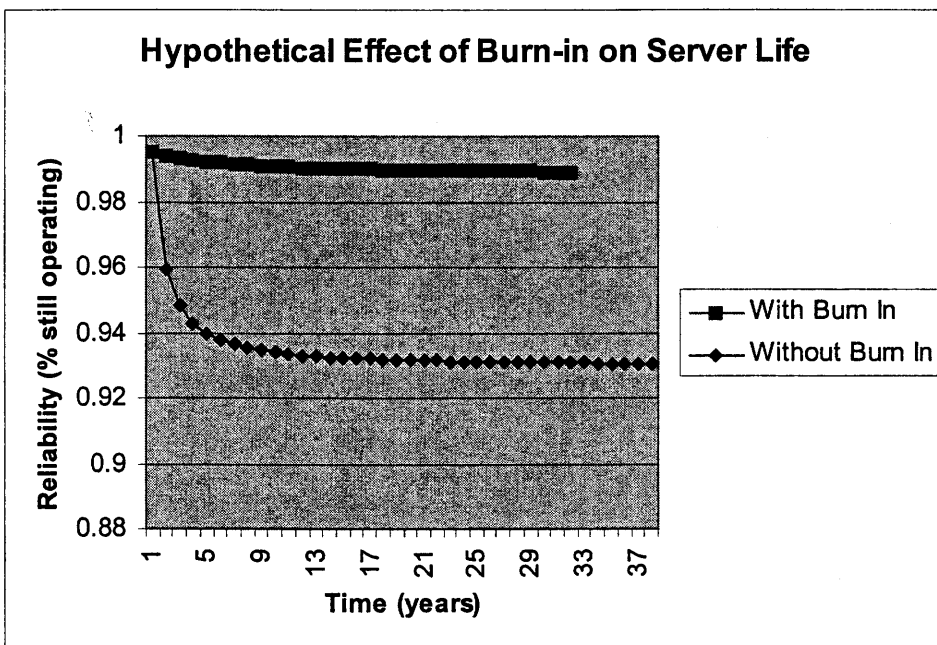


Figure 2-3. Comparison of failures from raw and burned-in parts.

The leveling section of the bathtub curve (the bottom of the bathtub) includes both early life and normal life distributions. It is possible for over 2% of the units fail in the first year, but it takes ten years for 3% to fail. In this model, there are still infant mortalities occurring well beyond ten years, but at an ever-decreasing rate. In fact, the integrated circuits (IC) industry has observed that with complex solid-state devices, even after ten years of operation, the primary failure type for ICs is still infant mortality driven primarily by defects rather than wear-out. Burn-in is useful because it screens a large percentage of the ELFs that would occur in the field. The remaining parts would be more reliable than the original population.

In reality, manufacturers do not have two to three years to spend on real-time burn-in, and therefore an accelerated stress test is needed. In the IC industry there are usually two stresses that are typically used to accelerate the effective time of burn-in: temperature and voltage. Increased temperature (relative to normal operating temperatures) can provide an acceleration of tens of times (10x to 30x is typical). Increased voltages (relative to normal operating levels) can provide even higher acceleration factors on many types of ICs. Combined acceleration factors in the range of 1000x, or higher are typical for many IC burn-in processes. Therefore, burn-in times of tens of hours can provide effective operating times of one to five years, significantly reducing the proportion of parts with infant mortality defects.

2.2.2 Server Product Quality

Published research relevant to the ELF project at Sun includes quality benchmarking and best practices in the management of field return units.

Quality Benchmarking for Servers

Failure rates are carefully guarded secrets in the computer industry, and company-specific benchmarks on ELF rates of servers are not generally available.

As noted by Gartner⁶, “we are not aware of any independent third-party organizations that are accurately tracking this information.” Gartner, however, does offer guidelines for failure rates of personal computers, which are summarized in Table 2-1.

Table 2-1. GartnerGroup’s PC Failure Rate Guidelines⁷

	Typical	Problematic	Serious Concern	DOA Rate Average	ELF Rate Average
Desktop	< 6%	6–10%	>10%	2%	2%
Laptop	< 20%	20–30%	>30%	3%	4%
Server	< 5%	5–10%	10%	2%	2%

Definitions: Typical: Within normal range — no action required. Problematic: Contact resellers and manufacturers, expressing concern and dissatisfaction. Serious Concern: Take immediate action with resellers and manufacturers, perhaps stopping or limiting further deployment until resolution, and begin to qualify alternative vendors

GartnerGroup also reports that the average number of failures for notebook computers within the first 60 days of purchase is 3% to 7%, although this is anecdotal. Finally, Gartner offers the following advice on failure rate monitoring: “Users need to track their notebook early failure rates. Early failure rates should not exceed 7%. A good practice would be to begin to put pressure on vendors when early failure rates go above 5%, as this is likely to be a warning that they could go higher. However if the early failure rate exceeds 5%, users need to take immediate action by making their resellers and manufacturers accountable, possibly even stopping shipment until resolution.”⁸

2.2.3 Business Processes for ELF Returns

Relevant literature for understanding business processes for ELF returns include examples of business processes that have been implemented as well as descriptions of data analysis techniques for ELF, failure modes, and methodologies for statistical analysis of failures.

When we speak of a business process for ELF returns, we refer to the process of material and information flow, and the chain of people involved at each step. To provide a skeleton business process for the following section, the process starts when a customer

⁶ K. Knox, Select Q&A, QA-06-7041, Research Note, GartnerGroup, 25 February 1999.

⁷ *Ibid.*

⁸ L. Fiering, K. Dulaney, Technology, T-04-1130, Research Note, GartnerGroup, 4 June 1998.

calls Sun to ask for assistance. Material and information then flow back to Sun. Data analysis is performed using information to determine priorities and resources based on issues and criticality. Failure analysis is performed on the returned equipment to find the root cause of the problem. The references cited in the following sections offer insight into how an ideal process can work.

2.2.3.1 ELF Prevention and Screening

Stress Testing⁹

ELFs are caused by defects designed into or built into a product. To avoid infant mortalities, the product manufacturer must determine methods to eliminate the defects. Appropriate specifications, adequate design tolerance, and sufficient component de-rating can help reduce ELFs and should always be used, but even the best design intent can fail to cover all possible interactions of components in operation. In addition to the best design approaches, stress testing should be started at the earliest development phases and used to evaluate design weaknesses and uncover specific assembly and materials problems. Tests such as HALT (Highly Accelerated Life Test) or HAST (Highly Accelerated Stress Test) should be applied, with increasing stress levels as needed, until failures are precipitated. The failures should be investigated and design improvements should be made to improve product robustness. Such an approach can help to eliminate design and material defects that would otherwise show up as product failures in the field. A stress test can still be valuable after manufacturing of a product begins. There are two distinct uses for stress testing in production. One purpose (often called HASA, Highly Accelerated Stress Audit) is to identify defects caused by assembly or material variations that can cause failure and to take action to remove the root causes of these defects. The other purpose (often called burn-in) is to use stress tests as an ongoing 100% screen to weed out defects in a product where the root causes cannot be eliminated.

It is usually most cost-effective to run 100% stress screens only for early production, and then reduce the screen to an audit (or entirely eliminate it) as root causes are identified,

⁹ D. J. Wilkins, "Hot Topics, The Bathtub Curve and Product Failure Behavior Part One - The Bathtub Curve, Infant Mortality and Burn-in," Reliability HotWire, Nov 2002.

the process/design is corrected and significant problems are removed. Some companies put 100% burn-in processes in place and keep using them, addressing the symptoms rather than identifying the root causes. They just keep scrapping and/or reworking the same defects over and over. For most products, this is not effective from a cost standpoint or from a reliability improvement standpoint.¹⁰

There is a class of products where ongoing 100% burn-in has proven to be effective. This is with technology that is “state-of-the-art,” such as leading edge semiconductor chips. There are bulk defects in silicon and minute fabrication variances that cannot be designed out with the current state of technology. These defects can cause some parts to fail very early relative to the majority of the population. Burn-in can be an effective way to screen out these weak parts.¹¹

Preventing ELF before they happen can be done through Design for Reliability (DFR). Oshiro presents DFR methodologies for IC design, including design flow and CAD tools.¹² They present a set of practical DFR tools and procedures have been developed and deployed to realistically manage product reliability throughout the design phase of a VLSI circuit. Infant mortality concerns are managed by insuring that the library is “robust,” by verifying the validity of test and/or burn-in screens.

A burn-in screen should be designed to have the appropriate test time. Use of the Duane model,¹³ which illustrates the method using the approximate times to failure, and the AMSAA model, which calculates the test times using the exact time to failure, can be used to calculate the percentage of product failing due to “infant mortality” reasons. Hamilton¹⁴, on the other hand, presents another calculation of test times based on MTBF.

¹⁰ *Ibid.*

¹¹ *Ibid.*

¹² L. Oshiro, R. Radojcic, “A Design Reliability Methodology for CMOS VLSI Circuits,” IEEE 1995 International Integrated Reliability Workshop Final Report (1995), 34-39.

¹³ V. Kane, “Calculation of Test Time Required to Remove Infant Mortality Failures [Product Quality Control],” APEC '92 Seventh Annual Applied Power Electronics Conference and Exposition Conference Proceedings (1992), 325-329.

¹⁴ C. M. Hamilton, B. R. Lewin, “An Approach to Developing an Infant Mortality Requirement for Fiber Optic Transport Systems”, IEEE Journal on Selected Areas in Communications, 8, no. 6 (Oct. 1988), 1444-1447

A cost-effective method, which analyzes the models to determine a point at which overall costs are minimized, is also presented. The appropriate test time of equipment before shipment is an important manufacturing parameter; if it is not long enough, not all potential ELF's will be captured in the test. If it is too long, valuable time and resources are used unnecessarily.

Although burn-in practices are not usually a practical economic method of reducing infant mortality failures, burn-in has proven effective for state-of-the-art semiconductors where root cause defects cannot be eliminated. For most products, stress testing, such as HALT/HAST should be used during design and early production phases to precipitate failures, followed by analysis of the resulting failures and corrective action through redesign to eliminate the root causes.¹⁵

Screening may also be performed without burn-in but by using direct input/output buffers leakage testing. Another screening test measures the power supply current while no internal node states are toggling.¹⁶ These tests are applicable when failures are caused either by the in-circuit components or the overall circuit performance degradation.

2.2.3.2 Data Analysis of Returns

Failure Modes

After a product has been released to the field and the product population shows early life failures, a process must be put in place to address customer complaints, reverse logistics, and the returns process in general. Methodologies¹⁷ exist for categorization of failures based on the failure log a server shows upon failing.

¹⁵ D. J. Wilkins, "Hot Topics, The Bathtub Curve and Product Failure Behavior Part One - The Bathtub Curve, Infant Mortality and Burn-in," Reliability HotWire, Nov 2002.

¹⁶ B. Lisenker, Y. Nevo, "Current Test for CMOS Early Failures Screening Suggests Two Tests That Can be Used to Screen ELF Units Before Sale," 1995 20th International Conference on Microelectronics Proceedings, 1 (1995), 231-234.

¹⁷ *Ibid.*

Lal and Choi¹⁸ demonstrate the classification of an event log data to calculate parameters such as MTBF and availability. Component analysis was performed to identify modules that are prone to errors in the system, and the system error activity preceding each system failure was analyzed to identify error patterns that may be “precursors” of the observed failure events.

Root Cause Analysis

Eliminating root causes is generally the best approach to quality improvement and can significantly reduce infant mortalities.¹⁹ In order to fix problems at their root, it is necessary to understand failure modes and their remedies. Understanding what the most common failure modes are is a critical step in determining ELF focus, and a number of articles shed some light on this topic. Conrad²⁰ describes a test methodology called operational life testing (OLT), which has been implemented to monitor and quantify the early-life reliability of selected semiconductor technologies and identify ELF mechanisms. This monitor measures the effectiveness of screens and tests used to remove device infant-mortality failure modes. In addition, the early-life reliability monitor complements the data derived from highly accelerated long-term reliability tests since it highlights specific failure modes which are not predominant in highly accelerated long-term reliability tests. Information gained from the monitor can be used to implement tests and screens designed to eliminate certain failure modes in a more timely manner than accumulating and analyzing field return data.

Jensen²¹ presents a model based on the assumption that all failures basically are due to wearout. He states that the only real difference between long-term wearout and the failures that occur in early life and during the useful life period will be in the size of the inherent flaws or defects in the components. Large flaws connect with early life failures

¹⁸ *Ibid.*

¹⁹ D. J. Wilkins, “Hot Topics, The Bathtub Curve and Product Failure Behavior Part One - The Bathtub Curve, Infant Mortality and Burn-in,” *Reliability HotWire*, Nov 2002.

²⁰ T. R. Conrad, R. J. Mielnik, L. S. Musolino, “A Test Methodology to Monitor and Predict Early Life Reliability Failure Mechanisms,” 26th Annual Proceedings Reliability Physics (1988), 126-130.

²¹ F. Jensen, “Component Failures Based on Flaw Distributions,” Annual Reliability and Maintainability Symposium 1989 Proceedings (1989), 91-95.

while small flaws connect with end-of-life failures. The model takes several competing failure mechanisms into account.

2.2.4 Data Analysis and Statistical Process Control

In Statistical Process Control (SPC), a failure may be considered an “attribute” because it cannot be measured numerically. Failures are measured as “defective” or “non-defective,” or “conforming” or “nonconforming.” A control chart, which allows statistical process control on field failures, may be created for fraction nonconforming or for nonconformities (number of defects in a population rather than the fraction).²²

Upper and lower control limits for such a control chart are given by:

$$\begin{aligned} \text{UCL} &= \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \\ \text{Center line} &= \bar{p} \\ \text{LCL} &= \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \end{aligned}$$

where the statistic \bar{p} estimates the unknown fraction of nonconforming fraction of failures. The statistic \bar{p} is the fraction on nonconforming units from a sample of the population, usually at least $n=20-25$.

Note that these limits apply for cases in which no standard is given. Analogous equations (substituting a the standard value, p , for \bar{p}) exist for cases in which a standard is given. The statistic \bar{p} is used if the true fraction nonconforming p is not known or if a standard value is reasonably set by management.

²² D. Montgomery, Introduction to Statistical Quality Control 4th ed., John Wiley and Sons, Inc., 286-287.

Chapter 3. Methodology

This chapter describes the approaches used 1) to gather data and 2) to devise a solution to ELF. Data gathering (the discovery process) occurred through interviews with individuals and through the ELF Tiger Team. The approaches for addressing the ELF process were process mapping and selection of a data analysis method for ELF data.

3.1 Discovery Process

Information on the current ELF returns process was gathered by interviewing managers and engineers in each of the relevant functional divisions. These divisions included Customer Service (“Sun Service”), Customer Quality, Operations, Engineering, and Management as well as groups at external manufacturers (contract manufacturers).

3.2 The ELF Tiger Team

A Tiger Team was formed to identify process gaps, to revise the ELF returns process, to devise solutions and recommendations, and to implement a new process. Members of the Tiger Team, and their titles and roles, are summarized in Table 3-1.

Table 3-1. The ELF Tiger Team.

Division	Title	Role in ELF process redesign
Operations	Director	Project Champion, LFM Sponsor
	Manager	Project Supervisor
	LFM Intern	Tiger Team Leader
	Systems Engineer	-
	Manager (UK)	-
	Engineer (UK)	-
Customer Service	Manager, IT and Database Architecture	-
Customer Quality	Director	-
	Statistician	-
Engineering	Manager	-
External Manufacturer	Manufacturing Engineer	-

3.3 Process Mapping

The ELF project aimed to improve operational efficiency as well as product quality. Operational inefficiency refers to the confusion that occurs when an ELF case arrives in operations and needs to be addressed. For instance, questions that may arise when an ELF case arrives include:

- Where did this product come from?
- Why did this product fail? (What were the error messages at the customer?)
- Where does this product go?
- Are there other failures of this type that can be referenced?
- Is this type of failure increasing or decreasing?

Alerts that generate such questions may come in a number of ways: from product received at a Sun Microsystems Volume Products Operations site, from a case that has “escalated” to a senior manager, from a monthly ELF report generated by Customer Quality, or from other sources, such as vendors.

Defining a business process for the routing of material and for data analysis could answer the questions listed above. Such a business process, described in a flow chart or company standard document, would clearly show handoffs and decision steps. Additionally, a business process for early life returns would improve operational efficiency, which enhances the company’s profitability.

Business process mapping has other purposes. While much of root cause analysis is done at the circuit level, root cause analysis can start at the business process level, and sometimes problems are found at this level. For instance, the root cause of servers failing could be due to the environment they are put into, such as insufficient air conditioning, irregular power regulation, dust, etc. In such cases, it would be useful to group and identify these failures before costly microelectronics diagnostics and disassembly takes place. In order to understand the entire scope of the returns process and to reference *ad hoc* issues, the returns process map would map end-to-end processes and problems (gaps), starting from a customer issue and feeding back to change implementation

(corrective action) in the design or process. As the process map illustrates from end to end, it can also be a tool to record and reference topics/problems for the team.

3.4 Evaluation of Data Analysis Techniques

Data analysis techniques can include Statistical Process Control or charting failures by cost-impact, failure, or root cause. Such a chart of the total number (or cost, etc.) of failures against the kind of failure on the x-axis is a Pareto chart. For example, one Pareto chart may include the total number of failures for each kind of component, such as CPU, disk drive, memory, etc. The appropriate data analysis can help prioritize corrective action efforts: data such as where failures are occurring geographically or under what user circumstances supply such indicators. As stated earlier, data analysis may also be used to find the root cause of an ELF and fix the problem for future products and processes.

Several methodological approaches were considered regarding ELF data analysis. “Voice of the Process” was an approach in which trends on systems and parts would be tracked on a month-to-month basis. Operations would respond if a component showed a sharp increase in the rate of early life failures. Time-dependent reliability may have considerable bearing on data analysis in order to assess the degree to which failures in the first stage of the bathtub curve (before a level failure rate) are captured and fixed systemically. Finally, paretoing of failures by variables such as part and failure type indicates what parts are causing the most failures and what fixes might have the most impact. The question posed to the ELF Tiger Team was which of these analytical methods should be used; therefore, evaluation of these methods was in the team’s final recommendation.

Chapter 4. Results

The results of this project were:

- An end-to-end process map of an ideal ELF returns process
- Gap analysis of the ELF returns process
- A data analysis framework
- Recommendations for implementation of the new ELF returns process

These findings will help establish a new ELF returns process that is both efficient and improves processes and product. The ELF Tiger Team itself as well as a pilot data analysis effort is also an outcome of this project. The results are discussed in more detail in the following sections.

4.1 Process Map

A process map was created for an ideal ELF returns process. A process map is a diagram of entities and activities at each stage, beginning from the customer complaint, mapping through failure analysis and change implementation, and ending in process assessment. The map (Figure 4-1 and 4-2) is based on the input of the ELF Tiger Team, which was comprised of the representatives from each of the functional groups in the process.

Description of the Process Map

The first page of the process map is a summary of top-level inputs and outputs (SIPOC, or Supplier-Input-Process-Output-Customer). The process is the ELF returns process. Customers supply product failures to the process. The output of the ELF process is documented failures, which have been corrected through data analysis, root cause analysis, and corrective action.

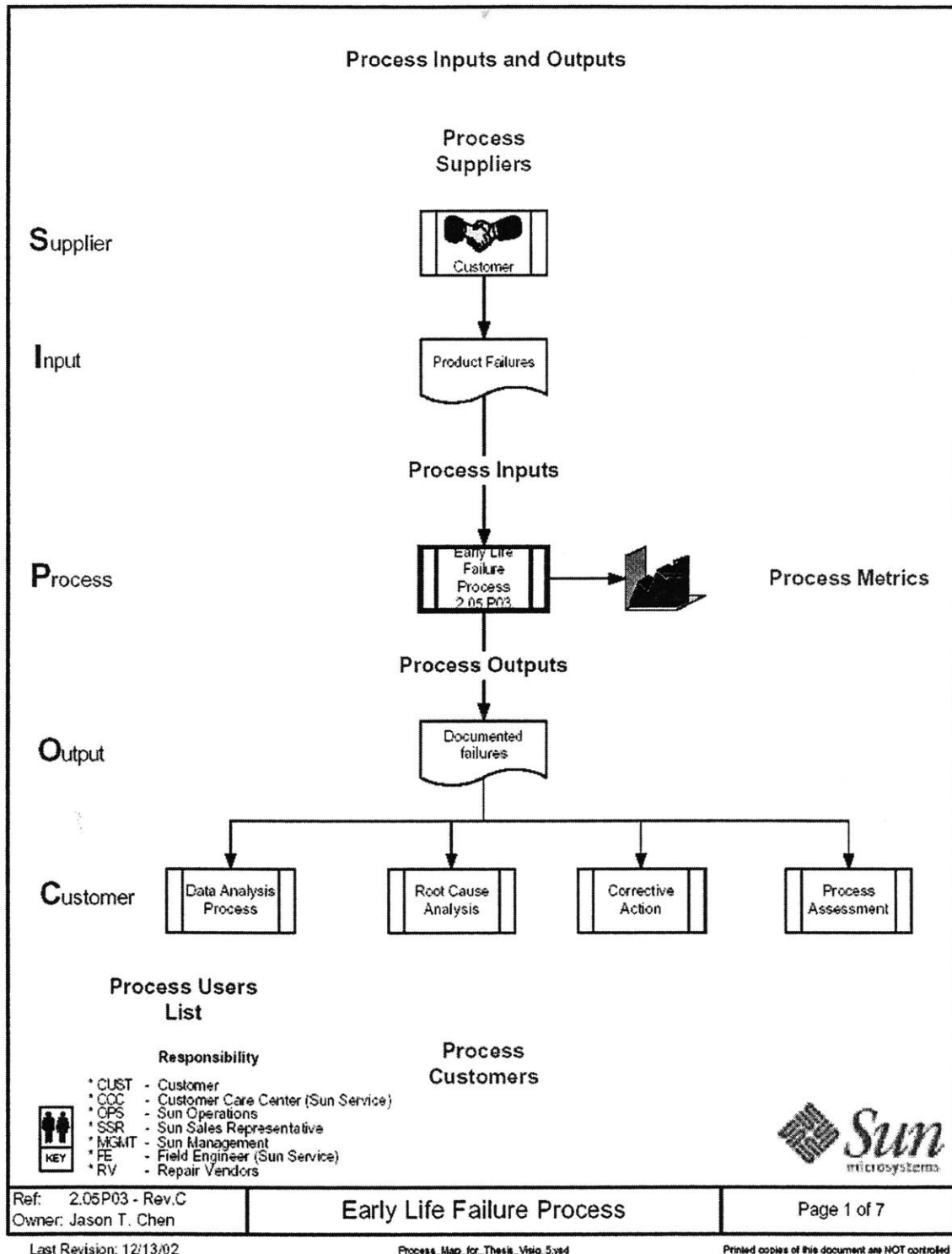


Figure 4-1. ELF Returns Process Map. Map continues for next six pages.

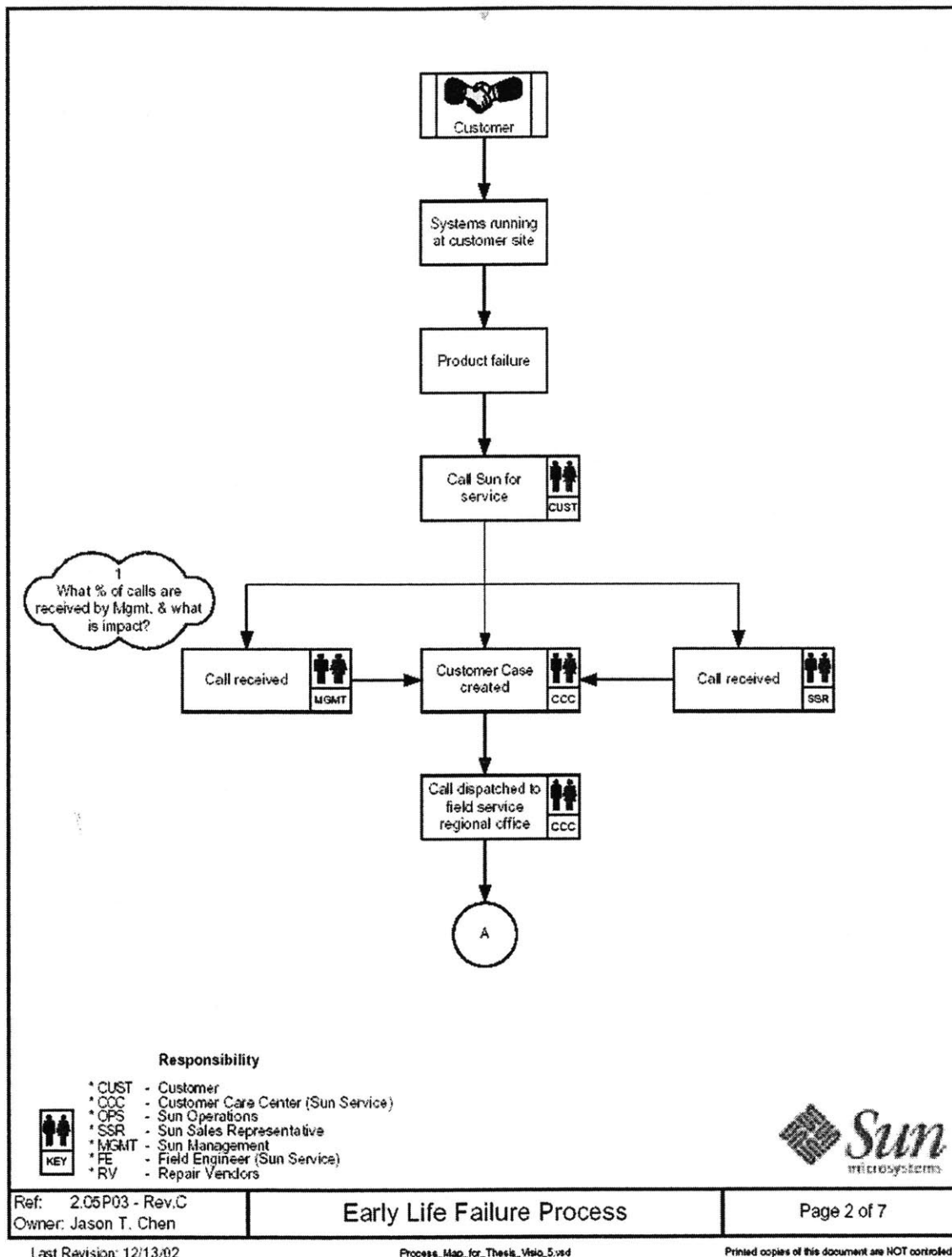


Figure 4-1 continued.

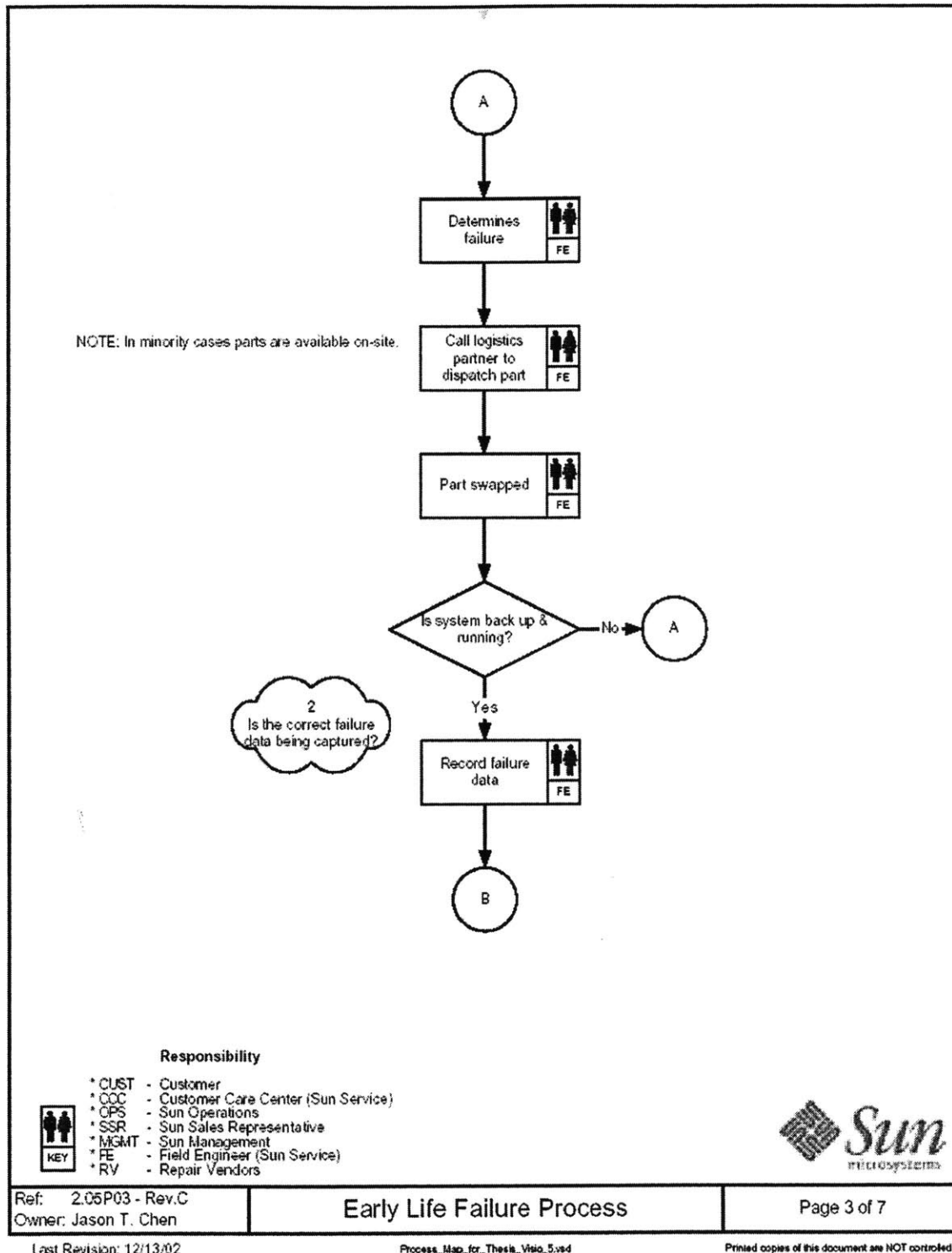


Figure 4-1 continued.

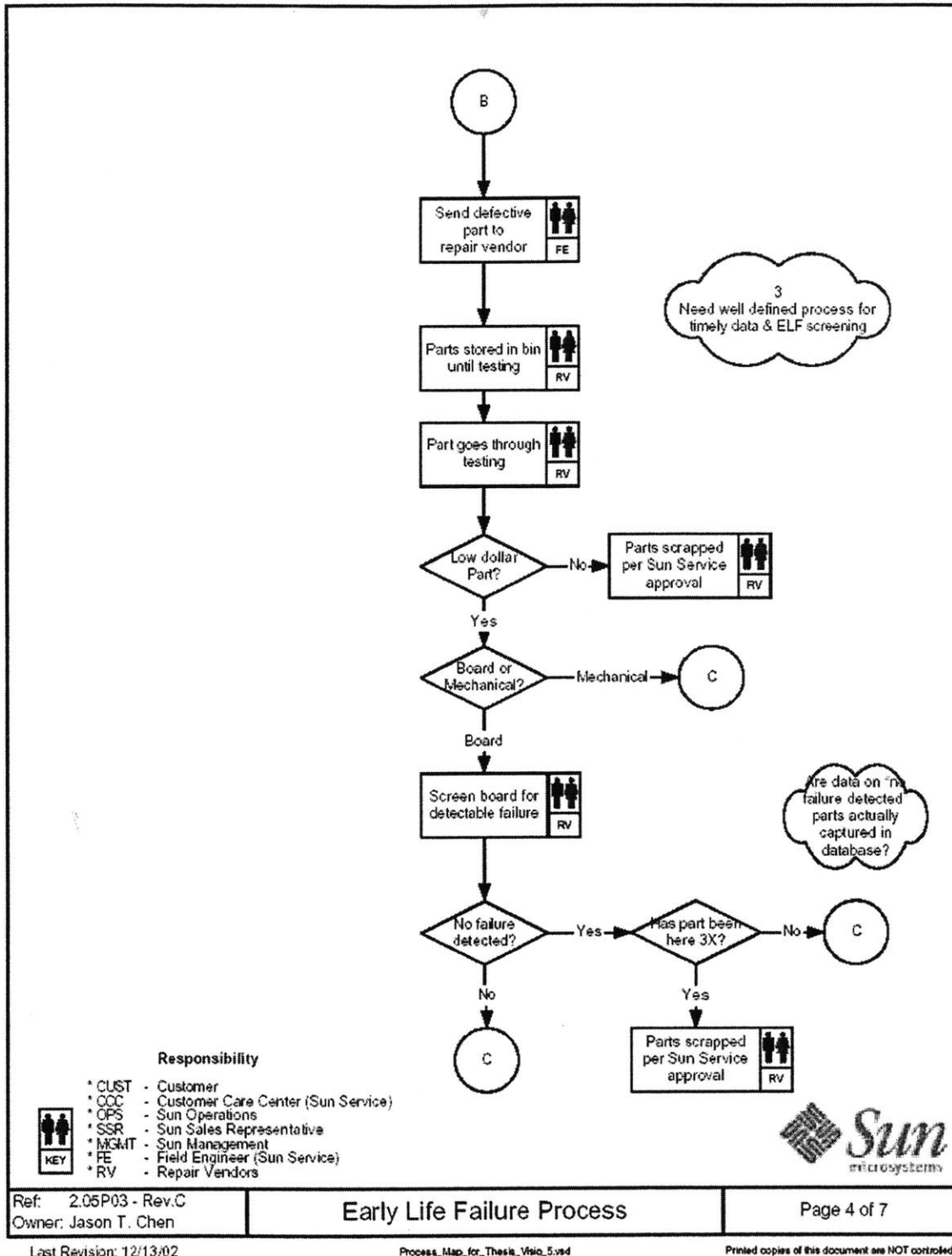


Figure 4-1 continued.

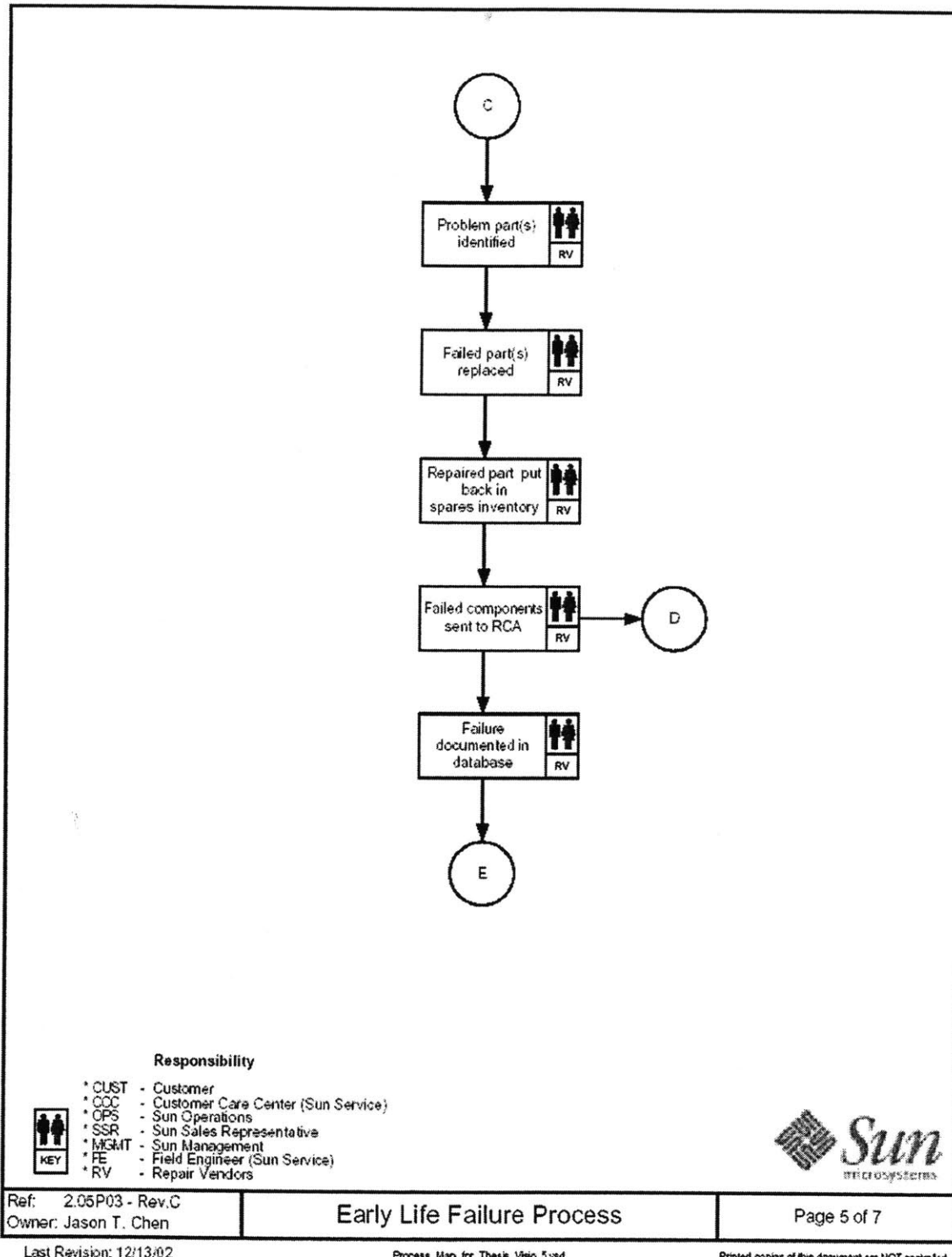


Figure 4-1 continued.

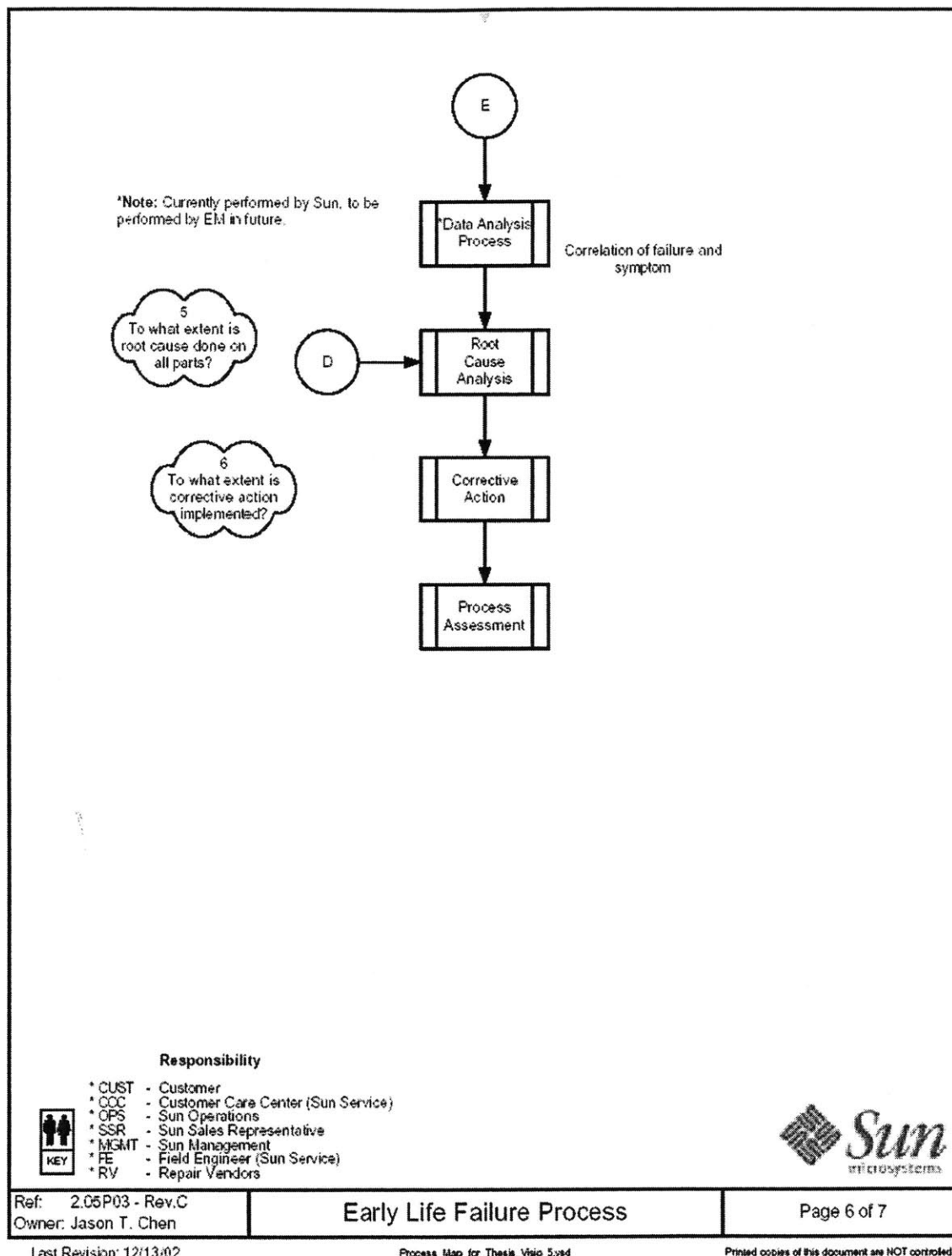





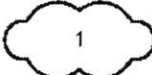


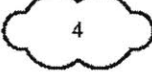

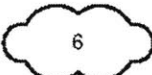


Figure 4-1 continued.

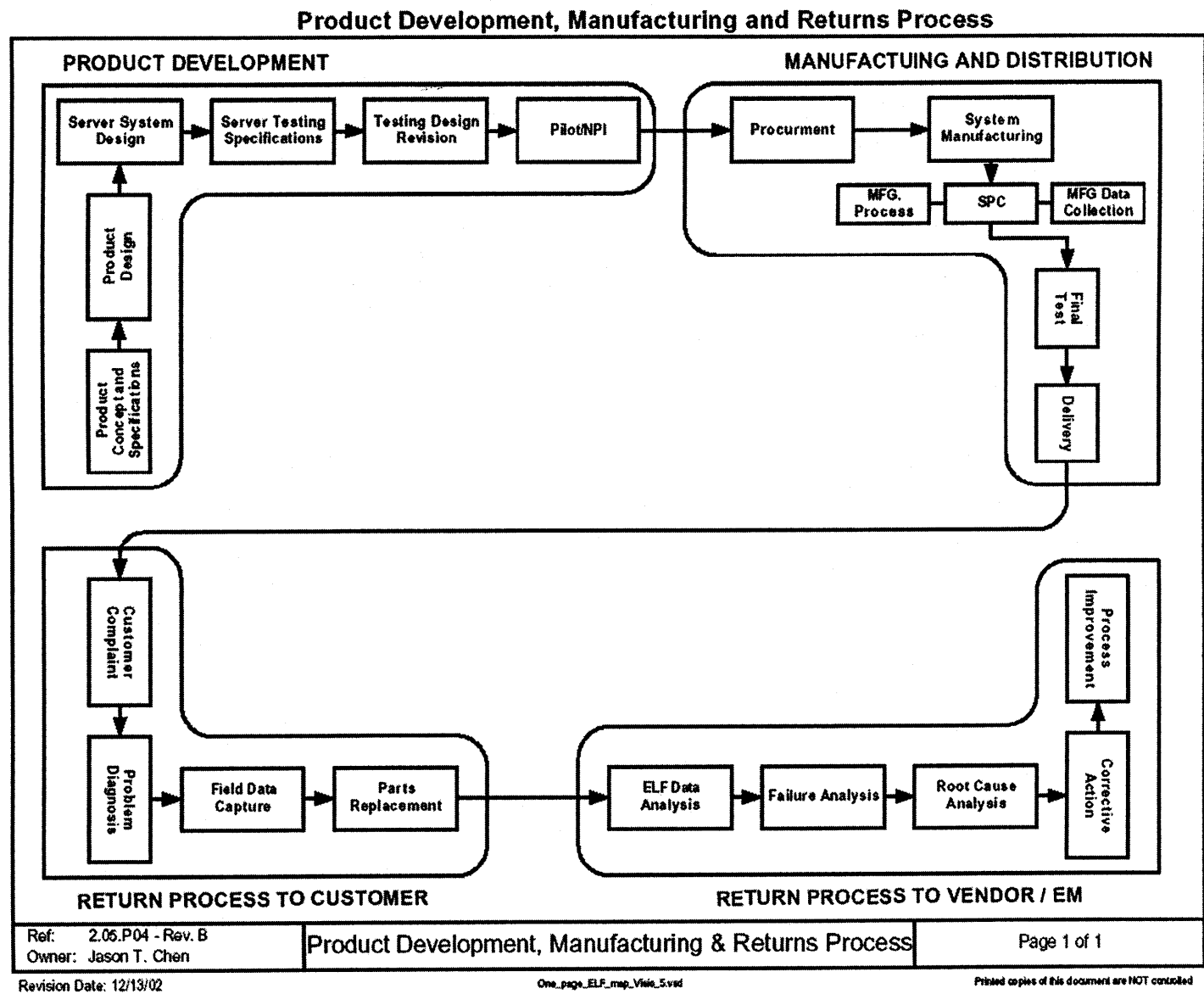
 Process Opportunities (6.04)	 Process Information, Methods and Instructions
  	Description Description of each Business Opportunity (ensure that there is sufficient detail to understand, prioritize and follow up).
	What % of calls are received by Management and what is the impact?
	Is the correct failure data being captured?
	Need a well defined process for timely data & ELF screening.
	Are data on "no failure detected" parts actually captured in database?
	To what extent is root cause done on all parts?
	To what extent is corrective action implemented?
Ref: 2.05P03 - Rev.B Owner: Jason T. Chen	<div>Early Life Failure Process</div> <div>Page 7 of 7</div>

Process_Map_for_Thesis_Visio_5.vsd

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Figure 4-1 continued.

Figure 4-2. ELF returns process "one-page" map.



The process map illustrates the standard procedure how a customer complaint is received and how the defective product is handled. While all customer complaints are received at a central location, dispatch of a field service engineer who will repair or replace the equipment is geographically based. Defective parts are shipped back to suppliers in different geographies rather than to a central Sun site for disposition. Information on the field failure is captured by the field service engineer and entered into the database at a later time.

Once a defective part, such as a motherboard, is received at the supplier, it undergoes failure analysis, in which the defective chip or part is identified. Failure analysis is different from root cause analysis, which aims to find the true cause of the failure, at the circuit or process level, for instance. Root cause analysis does not occur on all units, but rather on those requested by customer.

While there are many steps in common between the current and ideal ELF returns process, there are still some differences. The ideal map calls for a process assessment and process owner, which will be required for successful implementation. The ideal map also prescribes root cause analysis based on rational sampling, if not on all units. One of the features of the ideal process map is that monitoring of ELF levels and tracking specific ELF units will occur at the external manufacturer because this is the party that is running the actual manufacturing lines. The external manufacturer executes the manufacturing processes, acquires piece parts, and runs test equipment. Data analysis will be shared between Sun and the external manufacturer in order to pool best judgment on root cause focus.

4.2 Gap Analysis

Identification of gaps in the current returns process is necessary for implementation of a new ELF process. Gaps in the current process may be categorized as in Table 4-1.

Table 4-1. Categories of gaps in the ELF returns process.

Category	Gap
Incomplete Data	Failure data not entered or recorded at customer site
	Types of data missing or unorganized
	Data not recorded in enough detail
	Data not located in a central database
Business Process Gaps	Screening for ELF returns at manufacturing site
	No rules for data analysis and prioritization
	Sparse root cause analysis activity
	Sparse corrective action activity
	No process owner
Failure Analysis Issues	Failure diagnosis issues (e.g. multiple causes), including parts with no problem found

The following sections are a description of the gaps identified above.

4.2.1 Data

Data on ELF is often neither detailed enough nor complete. Lack of complete, accurate data makes it difficult for an engineer performing root cause analysis to find the problem. This issue is sometimes referred to as the issue of “data integrity.” An example is that an error message “System did not boot.” Such comments can be too vague, and the actual problem might be anything from a thermal failure (overheating) which could be diagnosed by a mechanical engineer to an electronic one (component shorting) which could be more aptly handled by an electrical engineer.

Data may be incomplete because of the current organizational structure. The primary responsibility of a field service engineer on a failure case is to make systems at the customer operational as quickly as possible. The engineer may do this by replacing defective or potentially defective parts with new parts as quickly as possible. The engineer has little incentive to capture detailed failure logs or interview the system administrator on what the conditions were at time of failure. Mitigation of this situation is discussed in more detail in Chapter 5.

All ELF data should be accessible from a central database. Because divisions of Sun representing different geographies have their own databases for capturing failure data, failure data in Europe, Asia, and the Americas are not connected. Non-aggregated data can drive inconsistent conclusions on highest Pareto failures due to variations in smaller populations. A centralized database is currently being built via a project developing new internal software.

Failure data collected at the customer and generated through failure analysis and root cause analysis should also be conglomerated. There are currently three different databases for ELF related information at Sun: 1) field log 2) failure analysis and 3) bugs (root causes). Information collected from the customer on the failure case is not located in the same database as data on failure analysis and root cause. If these data were in the same database, correlations of symptoms with causes could be made to steer future failure analysis efforts. Information on known bugs in design and software should also reside in the same database.

Sun's recognition that quality, facilitated by centralized ELF data, is increasingly important stems in part from the transition from technical end users to less technical users as business shifted from workstations to servers. In addition, the historically low rate of failures of Sun servers and the trend towards outsourced manufacturing may have placed a lower priority on the centralized design of databases for failure data. Indeed, implementation in only a specified geographic region (Europe or Asia, for instance) is easier than a global implementation, and regional divisions may not have had the interest or authority to integrate data globally.

4.2.2 The Returns Process

The absence of a standard business process is an issue in reacting to ELF problems across functional divisions. A business process is defined as a series of activities, people, and handoffs which efficiently achieves an end, and should exist for reacting to specific ELF failures, ELF alerts, or ELF metrics. The data analysis and root cause/corrective action gaps in the returns process are discussed in more detail below.

4.2.2.1 Data Analysis

One of the gaps in the returns process is that no standard data analysis technique was defined for understanding and improving ELF levels. A methodology for performing data analysis can help prioritize corrective action efforts. For example, data analysis may indicate prioritization of efforts by geography or by application. Data analysis may also be used to find the root cause of an ELF failure and fix the problem.

Potential data analysis approaches include 1) categorization of cases by total number of failures observed or by root cause 2) using statistical control techniques to monitor “acceptable levels” 3) identifying trends in customer, geography, or usage, and 4) performing root cause analysis on all returns or on a statistical sample. Among these alternatives for data analysis, statistical process control should be used to monitor ELF failures.

Of the four approaches to data analysis just mentioned, statistical process control is the preferred data analysis technique because it calls for activity only if ELF is out of control. In this case, “out of control” implies points outside of three standard deviations from a mean, based on running, historical averages. Control limits can be set on a chart of the fraction nonconforming (failures) for a specific model of server.

The implementation of Statistical Process Control (SPC) must be facilitated by a screen for ELF units at the repair vendor, often the contract manufacturer who manufactured the part. First, the contract manufacturer must identify ELF units among returns flowing in. The contract manufacturer can identify if a return is an ELF by the serial number of the part or system. The serial number of the system will give the date of manufacture.

Data on these ELFs may be grouped based on manufacture date. For instance, three of these groups may be the groups of units manufactured in March, April, and May. The number of failures received may be divided by the total number of units manufactured in that month to give the fraction nonconforming. The fraction nonconforming for a particular month will constitute one data point on the SPC chart. Once enough points are

plotted on this chart, control limits may be calculated for the chart, as described in section 2.2.4 Data Analysis and Statistical Process Control. If a point lies outside these control limits, investigation into the cause of a problem is called for.

It is important to note that the true time period over which the population experiences ELF will influence this SPC chart. Consider the situation of evaluating recent three months of data, say March, April, and May. The fraction of ELFs should be the highest in May based on the decreasing failure rate as observed on the bathtub curve. However, data for April will include two months' worth of ELF returns as compared to one month for May. A constant level of failures should exist in for months (time periods) greater than the time period of "early life" because early life occurrence decreases exponentially (Weibull). This constant level of failures after the ELF period should be used to calculate the historical mean value for fraction nonconforming.

The SPC approach will not identify processes that generate an unacceptably high number of ELFs but are consistent. If control charts show no points are out of control, the ELF data analysis team may consider continuous quality improvement on parts by highest occurrence or some other criterion.

4.2.2.2 Root Cause Analysis and Corrective Action

In order to decrease the occurrence of ELF, it is necessary to find the root cause of the failures and correct it. In the Volume Products division at Sun Microsystems, root cause analysis is offered as a part of customer service because customers expect Sun to be able to coherently explain what happened and how they will prevent future problems. However, root cause analysis should occur on a systematic basis, not only through customers' requests. A more effective process may determine what sample (number of units or kind of failures) should be tested through root cause.

Root cause analysis must be performed because types of failures may be permanently fixed by fixing their root causes. Implementation would take the following form: root cause analysis is performed on units identified as "out of control," e.g. servers

manufactured in May. A table of number versus kind of failure (Pareto) is plotted. Failure types may include gate oxide defect, mobile ion leakage, wire lead failure, or polysilicon defect. Correlations between root cause and symptom are generated and published (to design, system, process design team) to facilitate future root cause analysis.

Corrective action, resulting in engineering change orders to hardware or software or process improvements for instance, should occur as a natural consequence after root cause analysis. There was a lack of visibility to such activities, making enforcement, improvement, and tracking difficult. Root cause failure mechanism may be corrected at its source or at an effective point somewhat downstream. A quality policy based only on screening and reacting to failures, i.e. "correction by inspection," should not be used in place of understanding fundamental processes. Once root causes have been identified, corrective action must occur. Processes should be checked proactively to see that root causes found in the ELF analysis are avoided before they occur.

Chapter 5. Discussion

This section covers three main topics: 1) issues of the ELF returns process (the gap analysis) 2) financial effects of an implemented ELF returns process and 3) comments on implementation and change management.

5.1 Gap Analysis for the Business Process

As discussed in the results section, issues in the ELF returns process can be categorized into three main types: data, business process, and root cause analysis.

It is useful to think of three key issues in improving processes for ELF. First, the data integrity issue should be solved because it is inefficient to prioritize efforts based on inaccurate data. Second, a data analysis methodology is a critical piece of the process; a good methodology will show trends and uncover failure modes that are not otherwise obvious, whereas a poor data analysis methodology may be incomplete, misleading, or inefficient. Third, an emphasis on root cause analysis and corrective action will drive improvement that can be seen in future products and processes.

5.1.1 Data Integrity

Lack of data integrity may exist for a number of reasons. For instance, the Field Service Engineer (FSE) who replaces a defective part at the customer site may not be able to collect all the information available on how the part failed. He is motivated to minimize the time that the customer's system is down, which may cause impact his logging and documentation on diagnosis of the problem. An FSE only needs to understand a problem to the point where he can fix it with a replacement part. That is, servers may be repaired by replacing a Field Replaceable Unit (FRU), a module which contains a number of parts, not all of which will be defective at time of replacement. The FSE's performance is not measured on the completeness of the failure data (error messages) gathered, but rather on how many customers he can serve. In other words, data quality can be poor because of lack of incentives to gather all the data.

If the cause of a failure at the customer site cannot be identified, this situation may result in deflated ELF numbers because these cases will not be categorized. Systems, i.e. the server and its operating system, may not be designed in a way to give a meaningful error message. Indeed, if a part of the CPU is not working, that part may disable the computer's ability to report its own malfunction. The result is that genuine malfunctions are not captured in the ELF database.

ELF numbers are inflated when non-malfunctioning parts are removed. In order to expedite a repair, an FSE may not be able to take the time to identify a specific part that is causing the problem. Instead, he may replace the subassembly where the problem appears to lie. In some cases, a fully functioning subassembly may appear to have problems that are actually caused by something else in the system, such as a software error. Data collected in this case will inflate both type of failure and number of defective parts.

Misdiagnosis will also increase ELF numbers. An FSE may, at a customer site, identify a specific problem part. Upon return to the factory, however, the part may appear perfectly fine. This can inflate ELF numbers because the part has already entered the ELF database as a malfunctioning part.

5.1.2 Data Analysis

Given unlimited resources, root cause analysis and corrective action can be performed on each failure, and all reported ELF causes would thereby be corrected. As resources are limited in reality, the goal of data analysis is to identify prevailing failure types, modes, causes, etc. in order to improve quality in an efficient way.

Data fields may include applications running at failure, type and lot number of failed component, failure log and system model. No standard process exists for how to go about analyzing this data. For instance, should the ELF team examine trends in the conditions at failure or trends in failure rates of incoming electronic components? Should

decisions be made on the basis of number of failures, cost, or some other strategic criteria?

ELF alerts are already generated by statisticians in the Customer Quality group. Alerts are based on Pareto by part: a type of part, such as fan assemblies, are classified as “red,” or unacceptable, if the number of parts exceeds a limit that is either arbitrarily based or based on historical, but not statistical levels.

Without access to a specific failing unit, though, the engineer does not know how to react, what to do with existing data, or where to get additional data. At the top level, the ELF Tiger Team responsible for responding to ELF alert levels needs a rational decision process for resourcing ELF investigation and corrective activity. This prescription should be based on cost (e.g. return on investment), historical and best practices guidelines, activity on heaviest hitters, most important product, customers and segments, and the value of the time of the people. That is, efforts of the Tiger Team must be weighed against other activities they are responsible for, such as production, new product introduction, and supply chain/vendor management.

5.1.3.1 Statistical Process Control and “Voice of the Process”

Statistical Process Control (SPC) techniques, sometimes referred to as the “Voice of the Process,” are the recommended methodology for ELF data analysis. Unlike gross Paretos, SPC is a proven, rational, and statistical methodology, and gives credibility to data analysis. In addition, SPC offers techniques that allow us to track the process of the entire population rather than case-by-case issues or other scope-limiting approaches. Overriding corporate concerns, however, such as strategy and cost should be considered since these issues are not in the data analysis framework.

A number of approaches exist for tracking failures, failure types, and units using SPC techniques. For instance, one can easily imagine setting 3 sigma control limits on the basis of normalized (volume-adjusted) ELF failures for any particular component. Failures may be tracked by component, by system or across design revisions. But which

of these approaches is sound? For complex systems such as servers, the specific recommended approach is a control chart for nonconformities, as cited in the background section.

5.1.3 Root Cause Analysis

While the initial goal of the ELF project was to redesign the returns process to increase operational efficiency, it is important to recognize that quality in products and processes can be improved only by finding and correcting root causes. Employing “patches” to correct or mask individual errors is not an acceptable solution; the root cause of a failure must be identified and fixed.

There is a wide variety of root causes for a failure because the design and manufacture of a server is complex. A server can fail due to defective electrical or mechanical components, erroneous connections, or faulty system design. Failures can result from errors in the manufacturing process or defects in materials. In order to find the root cause, individual components may need to be disintegrated and their circuits may be examined under microscope or other analytical technique. Apparent failures may be caused by imperfect software and operating systems. Diagnosability, dependent on a comprehensive set of software-driven tests of component features, is often inadequate to identify precisely the root of an error. At times, a failure has no explainable cause.

The complexity of the value chain complicates root cause analysis coordination. In the Volume Products division at Sun Microsystems, servers are generally assembled at a non-co-located external manufacturer. Subassemblies, such as PCB boards, fan trays, or enclosures, may be manufactured by upstream suppliers. Electronic components may also be manufactured by a number of different vendors. Thus, server manufacturing has multiple companies at each stage of a multi-link value chain. Diagnosis for failure or root cause analysis is best done at the site of assembly or of component manufacture. In order to address root cause analysis on a returned server, one must at some point identify where in the value chain the root cause analysis will be done. Obviously, if the exact

problem is not known, as is often the case, it is difficult to route an ELF case to its appropriate location.

5.1.4 Incorporating Best Practices into the Returns Process

As described in the background section, the following changes are recommended to improve the business process for returns at Sun Microsystems: categorization of failure log info, correlation of root cause with failure type, and calculation and application of appropriate test times (at burn-in) to screen new product before release to the field.

5.2 Return on Investment and Cost of Quality

In evaluating the overall financial impact of instituting an improved ELF process, we consider three primary factors: 1) increased revenue (and profit) from customer perception of improved quality 2) dollars saved from operational efficiency resulting from a defined ELF returns process and 3) cost/investment in the ELF process, i.e. teams, structures, cost of implementing improvements. Here, we are trying to assess the “cost of quality” or “return on investment” of an improved ELF response process as compared to the current state.

An equation adding the dollar impact of these three factors was created, and the calculations are shown in the Table 5-1. The impact of implementing the new ELF process is roughly \$21.5M additional profit to Sun annually. Key assumptions in this model are that sales will increase 0.5%²³ based on customer perception of improved quality and that investment in an ELF business process is of the order of \$15M annually. While operational efficiencies are anticipated as a defined process makes activity more coordinated, we assume that its the financial impact is nil because more new activity is taking the place of minimal, confused activity. Based on these rough calculations, a new ELF process is justified.

²³ 0.5% increase in revenue is an estimate based on the increase in market share of an average computer manufacturer if that company were improve their brand (“brand effect”). The assumption here is that computer quality among manufacturers is the same while consumer perception of it drives differences in market share. Change in market share = $\exp[.1] = 1.1\%$ increase. If Sun has 50% market share in midranges servers, then 0.5% revenue increase is a reasonable estimate. Ref: J. Stavins, “Estimating Demand Elasticities in a Differentiated Product Industry: The Personal Computer Market,” Journal of Economics and Business, Jul/Aug 1997, 49(4), 347

Table 5-1. ELF return on investment.

	Annual Impact	Detail	Note
	\$ 25,000,000	increase in profit due to increase in quality	1
+	\$ -	operational efficiency	2
-	\$ 2,000,000	marketing and communication expense to customers on ELF	3
-	\$ 1,500,000	investment in new ELF process, annually	4
Net effect:		\$ 21,500,000	

These figures were calculated as follows. Note that these numbers may not accurately reflect proprietary financial details, but are meant as a feasible estimate.

- 1) Increase in profit due to improved quality was the product of: the revenue of FY 2002 (\$12.5B)²⁴, margin (40%), and increase in sales due to improved quality (0.5%). The percentage increase in sales was estimated at 0.5% based on the price-quality elasticity for computers presented by Stavins. (See preceding footnote.)
- 2) Time and energy expended may be the same since an inefficient, unexecuted process requires as much effort as defined processes for more cases. Quality improvement in the latter case are higher.
- 3) Marketing and communication relating to ELF quality may consist of brochures for sales persons, advertisements in appropriate magazines, etc. The amount is a rough estimate
- 4) Investment in a new ELF process, as described in section 5.3.2 Cost of Implementation, is estimated at \$1.5M annually.

If the failure rate of servers is already very low, customer may not appreciate or perceive the improved quality level, and revenues may not correspondingly increase. Another consideration is market share: in markets where Sun has a dominant position, it may not be possible to increase it in a measurable way.

Some quality philosophies, such as the Toyota Production System, may seem to advocate blind devotion to improving quality without regard to implementation cost. However, the

²⁴ Financial statements for Sun Microsystems at Yahoo! Finance Website. Available from <http://biz.yahoo.com/fin/l/s/sunw.html>.

benefits of this manufacturing philosophy have been proven. For instance, consider the celebrated Andon cord in Toyota's automobile manufacturing. While stopping the manufacturing line may seem costly, this emphasis on quality actually has a positive net effect on revenue.

5.3 Change Management and Implementation

This section describes recommendations on how to put the ELF Business Process in place at Sun Microsystems. Theoretically, one could distribute a business process model to parties involved with returns and the process would run smoothly from that point forward. In reality, change management and successful implementation rely on a number of human factors, such as organization structure, incentives, and leadership. This section also reports on progress of a pilot data analysis team, which is the first step in the institutionalization of the process.

5.3.1 Current Implementation

The goal of the ELF project during the seven-month LFM internship was to understand the ELF returns process and to take steps towards improving the situation. The first steps towards this end have been taken: creation of a process map, definition of a data analysis methodology, and establishment of an ELF Tiger Team. A Data Analysis pilot is underway to demonstrate outputs of the methodology on real data from most recent months.

However, it will take time to implement a new ELF returns processes and policies in Sun, or even in just the Volume Products Operations group in Burlington. In Volume Products Operations in Burlington alone, coordination with the analysis team who are not co-located, such as at Sun in the UK or at the external manufacturer, could slow the change process. The new ELF process will be reflected in process metrics across these groups, firm understanding of the process (e.g. stakeholders' understanding of the process), number of cases resolved with corrective action implemented, and ultimately, customer satisfaction achieved.

5.3.2 Costs of Implementation

This section describes the investment costs of a new ELF returns process. Key pieces of a new ELF infrastructure and their costs are described in Table 5-2.

Table 5-2. Cost of implementation.

Change needed	Description	Cost (1 st year), fully burdened
ELF screening at the repair vendor/contract manufacturer:	3 returns engineers and 3 data analysis engineers at 3 repair vendors globally. Returns warehouse space and IT for an ELF database.	\$100K for 6 people per year, ELF warehouse space ~ \$0 IT for ELF tracking \$100K, including IT architect
Increased root cause analysis and corrective action	Cost from repair vendor for diagnosis and repair of problem	Estimated charge of \$200/repair case. Sampling size of 30 cases/month. Total = \$72K + overhead = \$100K
Process owner	Manager at Sun responsible for driving change, should implement changes recommended from gap analysis	\$150K
Data analysis	Tiger team time and effort required	Time involvement of eight individuals for 2-3 hrs/wk: \$100K/year
Diagnostics redesign	Time required by test and design engineering	Estimated: \$200K/year for time and personnel
IT	Centralization of databases at Sun (already underway)	\$100K: ELF share of databases undergoing reconstruction

These figures are meant as an estimate of costs to assess the magnitude of investment in a new ELF returns process. The total investment in the first year is \$1.35M. Investment in the process in future years may decrease slightly because the investment in IT and diagnostics has been made. However, expansion of ELF efforts to cover more geographies or to implement continuous improvement may require similar investments.

5.3.3 Leadership and Changing Mental Models for Returns

The process owner, the process champion, and senior management are responsible for influencing the organization to implement change. Direct communication is also an important tool for management to address top-level goals. Large meetings (“All Hands”) can facilitate common understanding among teams that ELF is a priority. Rationale given by top-level management can help employees understand the strategic motives behind directives, such as the necessity for customer focus. At the same time, management should consider, and address to everyone, the balance that needs to be struck between ELF focus and other strategic goals, with consideration to return on investment, cost of quality, quality philosophy and implications, and Sun strategy and quality.

The success of the ELF returns process depends not only on people’s understanding of its significance to the company goals but also the process itself. ELF serves the company goals by improving customer satisfaction. The goals of the ELF returns process are continuous improvement, product quality, and customer satisfaction. A working understanding of the process includes a process map and knowledge of who is involved in the process.

People involved in the returns process include engineers and managers at external manufacturers, especially since much of the failure analysis is done at these companies. A committed process owner and a process champion (at a senior level of management) should be responsible for seeing that the process works effectively. A commonly understood deliverable between management and the ELF Returns Process Owner should exist. Such a deliverable may simply be the list of the top three failure types that will undergo root cause analysis in a specified period of time based on SPC charts.

The formal design of the organization may hinder project efforts because individuals working in cross-functional silos are motivated by their group goals. ELF, on the other hand, requires cross-functional coordination and, more importantly, do not have metrics

which individuals are measured on. For instance, it is critical to obtain failure data of a server before it is repaired or shipped back to Sun. Again, the Field Service Engineer responsible for the repair is motivated to increase the speed of repair and not to collect of failure data. Even among parties committed to improving ELF, such as members of the ELF Tiger Team, logistical hurdles exist in the coordination of efforts because individuals are geographically dispersed. Meetings among members from California, Massachusetts, the United Kingdom, and other locations required teleconference-only meetings.

In order to implement the recommendations more easily, drivers for quality should exist as integral part of all groups involved. Individuals are needed in design to ensure that the proper test procedures will exist for ELF screening. Operations will require a representative to respond to ELF alerts and to manage the ELF process. While it is not clear that ELF needs to be the primary responsibility of the individuals driving this change in these organizations, other groups will need someone who will ensure that critical ELF-related tasks get attention. A facilitating step towards moving the entire organization towards executing a new ELF process is a company-wide process redesign.

Incentives are important for implementation of a new process. Goals for individuals and for teams should be aligned with ELF goals. Some examples of incentives are: bonuses based on concrete goals for a project team or division, organizational definition of job roles, or re-organization which focuses on end-to-end customer quality. Metrics and accountability in measuring the performance of individuals and goals and priorities for groups are also important.

Change management begins with the understanding that Sun seeks competitive differentiation through product quality. Sun's expanding product line as well as the maturity of the market, e.g. customer knowledge, requirements, and power, will require well-designed and executed quality systems and business processes. Sun management is challenged to foster an environment that has an obsession with quality without losing innovation.

Chapter 6. Conclusion

Early life failures are an important quality measure for Sun Microsystems. The ELF project was initiated to understand and improve the ELF response processes. Motivations for this work included: using quality as a competitive advantage, efficiency/cost-effectiveness in the returns process, and continual improvement as a quality philosophy.

Process mapping is an effective way to identify gaps in a business process. For the ELF process at Sun, gaps were found in ELF data and in the business process. Data issues included non-centralized data and incomplete reporting of failure, which hinders diagnosis. Business process gaps included no standard method for data analysis and execution of root cause and corrective action. A process owner and process metrics are important for ELF activity on an ongoing basis.

ELFs impact both product quality and operational efficiency. A process to manage ELF returns will involve logistics, data analysis, and failure analysis. For implementation of a new ELF business process to be effective, change must be managed actively, through company-wide emphasis, metrics, and incentives.